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Review article

Mining and climate change: A review and framework for analysis

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ABSTRACT

In this paper, we demonstrate that climate change is critically important for the current and future status of mining activity and its impacts on surrounding communities and environments. We illustrate this through examples from Latin America, including a spatial analysis of the intersection between projected climate changes and existing mining operations. We then elaborate a framework to identify and investigate the relationships among mining, climate change, and public and private responses to them. The framework also notes the importance of political economy and learning processes to the forms taken by these relationships. Our paper then reports on a focused review of peer-reviewed publications that aims to identify the extent to which a core research literature on mining and climate change currently exists. We show that this literature is still very limited, but that the analysis that does exist can be encapsulated by the main elements of our framework. This enables us to describe the current structure of both peer-reviewed and policy research on mining and climate change, and identify areas for future research. In particular, we note the chronic absence of research on this relationship for the vast majority of developing countries, where some of the most serious vulnerabilities to climate change exist.

I. Climate change as an emerging driver of mining policy

On March 29, 2017, El Salvador's Legislative Assembly unanimously passed a law banning metal mining in the country. "El Salvador makes history as first nation to impose blanket ban on metal mining" The Guardian (2017) stated, while *The New York Times* (2017) reported that "El Salvador, Prizing Water over Gold, Bans All Metal Mining." Though passed by a left-of-center government of the Farabundo Martí National Liberation Front (FMLN), conservative, pro-market, anti-regulation lawmakers of El Salvador's Nationalist Republican Alliance (ARENA) also voted for the law. Reflecting on that vote, one of these ARENA legislators, Johnny Wright Sol, "who worked to persuade his business-friendly party to support the law, said that climate change was already having an impact on El Salvador. 'More than a theory or an uncertain science that it might have been 10 years ago, today for Salvadorans, it is a reality'"(*New York Times*, 2017).

El Salvador's law points directly to the increasing significance of climate change for strategic decisions on the regulation of mining. For several years prior to the law, critics of the mining sector in El Salvador had been drawing attention to the vulnerability of the country's water resources under conditions of climate change, and argued that to allow mining in the country would aggravate this vulnerability (Broad and Cavanagh, 2015; Spalding, 2013; Moran, 2005). A Strategic Environmental Assessment of the mining sector also noted that mining would use water resources that climate change would make scarcer, and that the increasing frequency of severe storms would threaten the failure of tailing dams and other mine infrastructure, with potentially serious consequences for water contamination (TAU, 2011; Bebbington et al., 2015).

Though perhaps an extreme example, the case of El Salvador demonstrates the significance of climate change for the future of the mining sector, particularly in water-constrained national environments. Indeed, even in a mining-country *par excellence* such as Chile, a senior executive of a leading global mining company insisted that climate change-related pressures on water and energy resources demand that the sector go through "a socio-technical regime change," not only as an adaptive response, but also because in a context of climate change, "the forms of gaining legitimacy have changed." A leader from Chile's national mining sector expressed a similar view, arguing that innovations related to water and energy had to be accelerated, not least because in the future, companies and metals are likely to be assessed in terms of their climate footprint.[1]

These emerging developments within at least some policy and industry communities draw attention to a relative lacuna in the academic

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[1] Interviews with second author on March 5 and 9, 2015, in Santiago, Chile.

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literature, where, we contend, the relationship between mining and climate change has received limited attention. This gap is borne out by a simple review of titles in this journal, one of the principal academic venues for debate on extractive industries. Since its founding, it has published no articles that have references to climate change in their title (though Holden's article on typhoon vulnerability deals with climate change risk: Holden, 2015). The scholarly literature on mining has been more concerned with themes such as: the relationships between extractive industry and development; extractive industry governance; community rights; consultation and resistance; the social and environmental impacts of extractives; corporate social responsibility; and, increasingly, artisanal and small-scale mining (ASM). This is not a criticism, but we do suggest that the literature is not yet equipped to speak to what seems likely to become a critical driving factor in extractive industry governance.

Given this lacuna, this paper does four things. First, in the following section, it develops the claim that climate change is a critical issue for the mining sector by presenting evidence on likely future relationships between mining and climate for the case of Chile. The data presented, in the form of maps, demonstrate clearly the potential for a spatial overlap between climate change impacts and mining operations, particularly in areas where water use by mines is of concern. This Chilean material is presented *not* as a fully developed case study that runs through the paper, but simply to make the point that climate change is an empirical problem for mining, not just a political problem. Second, the paper develops a simple framework for organizing thinking around the climate change-mining relationship. The framework is developed deductively, and describes a set of relationships that, we argue, structure how mining and climate change interact, and which require much deeper investigation by scholars. Third, the paper conducts a two-step review of existing literature in relation to this framework. The first step focuses on that smaller body of peer-reviewed publications that addresses the topic of climate change and mining as part of their main purpose. This initial review seeks overall patterns in this literature and shows that existing work falls within the relationships addressed in our framework, suggesting that the framework effectively captures the primary concerns of scholarly work to date. The second step of the review then offers a more in-depth discussion of both this literature and a broader set of existing research related to climate change and mining using the framework as an organizing structure. Finally, the paper uses this review and our framework to assess possible research agendas.[2]

II. Climate change and mining in Chile: visualizing the challenge

In this section, we examine the potential spatial relationship between climate change and mining, using the case of Chile as an illustration.[3] The purpose of the analysis is to give empirical support to the claim that climate change already is, and will continue to be, a critical issue confronting mining. Chile has employed mining to drive its economic development, and is the world's largest producer of copper. Its mining sector accounted for 54% of national exports and 12% of GDP in 2015, and an average of nearly 20% of annual government revenue between 2004 and 2015 (COCHILCO, 2010, 2015). Since the country's return to democracy in 1990, this development model has helped Chile to maintain one of the highest average GDP growth rates in Latin America and a decrease in both poverty and inequality (World Bank, 2016). The mining operations driving this growth are concentrated in the country's arid northern regions—some of the driest areas on Earth—leading to water scarcity and conflicts with local communities over access to water, water contamination, and community rights to livelihood (Babidge, 2016; Budds, 2010; Prieto, 2015, 2017; Urkidi, 2010). Small climatic changes in these mining regions could therefore have severe consequences for mining operations, local communities and environments, and the country as a whole.

Fig. 1[4] shows projected changes in mean annual temperature in Chile from current (1970–2000) levels to 2050, and where they overlap with mines (including small, medium, and large-scale operations) presently operating in the country (as of 2011 and 2012). Fig. 2 does the same for total annual precipitation in the country. Fig. 3 offers a frequency histogram of the number of mines shown in Figs. 1 and 2 that are projected to experience a given change in mean annual temperature (a) and total annual precipitation (b) by 2050. The climate projections are based on two different Representative Concentration Pathways (RCP) employed by the Intergovernmental Panel on Climate Change (IPCC) in its most recent Assessment Report (AR5). RCP 4.5 represents an optimistic scenario in which the amount of energy added to the earth's atmosphere increases by 4.5 W/m^2 over pre-industrial levels by 2100. In contrast, RCP 8.5 assumes a pessimistic trajectory for current anthropogenic greenhouse gas (GHG) emissions, in which energy in the atmosphere increases by 8.5 W/m^2. Conclusions from these figures should be drawn with caution, as they represent a basic exercise in examining the potential relationship between climate change and mining in only one country, using only one Global Concentration Model (GCM). Moreover, precipitation levels are known to be particularly difficult to predict, lending more confidence to Fig. 1 than Fig. 2 (Hegerl et al., 2015; IPCC, 2014a: 42).

Despite these caveats, the figures present information that can be useful in examining the potential spatial relationships that may emerge between climate change and mining, particularly in water-scarce regions. Figs. 1 and 3a indicate that most of Chile's mines will experience an increase in average annual temperature of between 1 and 3 °C by 2050 under RCP 4.5, and between 1 and 4 °C under RCP 8.5. Interestingly, Figs. 2 and 3b predict a slight increase in precipitation in most mines under both RCP 4.5 and RCP 8.5. These absolute measurements of precipitation change, however, mask differences in relative impact between regions that receive divergent amounts of rain in the same period. That is, the Atacama Desert in the northern region—the site of many mining operations—is considered one of the driest areas on Earth, and thus, even miniscule changes in precipitation (positive or negative) could have far-reaching ecological and social consequences (see, for example, Bozkurt et al., 2016).

Moreover, higher temperatures could increase the rate of glacial melt along Chile's Andean chain, which could have substantial impacts on water availability given the country's dependence upon runoff (Bellisario et al., 2013; Fiebig-Wittmaack et al., 2012). Glacial melt leads initially to an increase in run-off and associated water availability, followed by a long-term decline (Bury et al., 2013; Magrin et al., 2014).

[2] In doing so, we build off of and expand upon Phillips' (2016) recent literature review. While he reviews existing research with an eye to the potential physical implications of climate change in terms of biophysical, chemical, ecological, and hydrological processes, we seek to elucidate both the physical and social interactions between climate change and mining, as they play out in socio-economic processes, industry practice, public policy, public perceptions, and actual physical outcomes.

[3] We could have chosen a number of countries or regions with similar dynamics to demonstrate the spatial relationship between climate change and mining, but selected Chile due to the authors' familiarity with the case, and the availability of necessary data.

[4] Data sources for Figs. 1 and 2: **Basemaps**: (**1**) Chile administrative boundaries: "DIVA-GIS, " n.d. (**2**) Global boundaries: "DIVA-GIS," 2011. **Mine sites**: (**1**) Data from SERNAGEOMIN, 2011a, 2011b, 2011c, 2012a, 2012b. (**1.1**) These "atlases" offer mining data for Chile by region and commune. We identified mine sites by isolating all operations listed in these documents as having an "Installation Type" (*Tipo Instalación*) of either "Open Pit" (*Mina Rajo Abierto*) *or* "Subterranean" (*Mina Subterránea*), and a status (*Situación*) of "Active" (*Activa*), regardless of operation size or material mined. The total number of mines identified was 1027. (**1.2**) Special thanks to Christoph Albers of *Cartografía Rulamahue* for identifying these documents, which he used for his map, "Mines," under the section "Economy," at this citation: Albers, 2016. **Current Temperature and Precipitation**: (**1**) Fick and Hijmans, 2017 (via worldclim.org). (**2**) All data were downloaded with a spatial resolution of 10 min. **Future Temperature and Precipitation**: (**1**) Hijmans et al., 2005 (via worldclim.org). (**2**) All data were downloaded with a spatial resolution of 10 min. (**3**) The HadGEM2-ES GCM was selected following Chou et al.'s (2011) use of it for climate change analysis in South America.

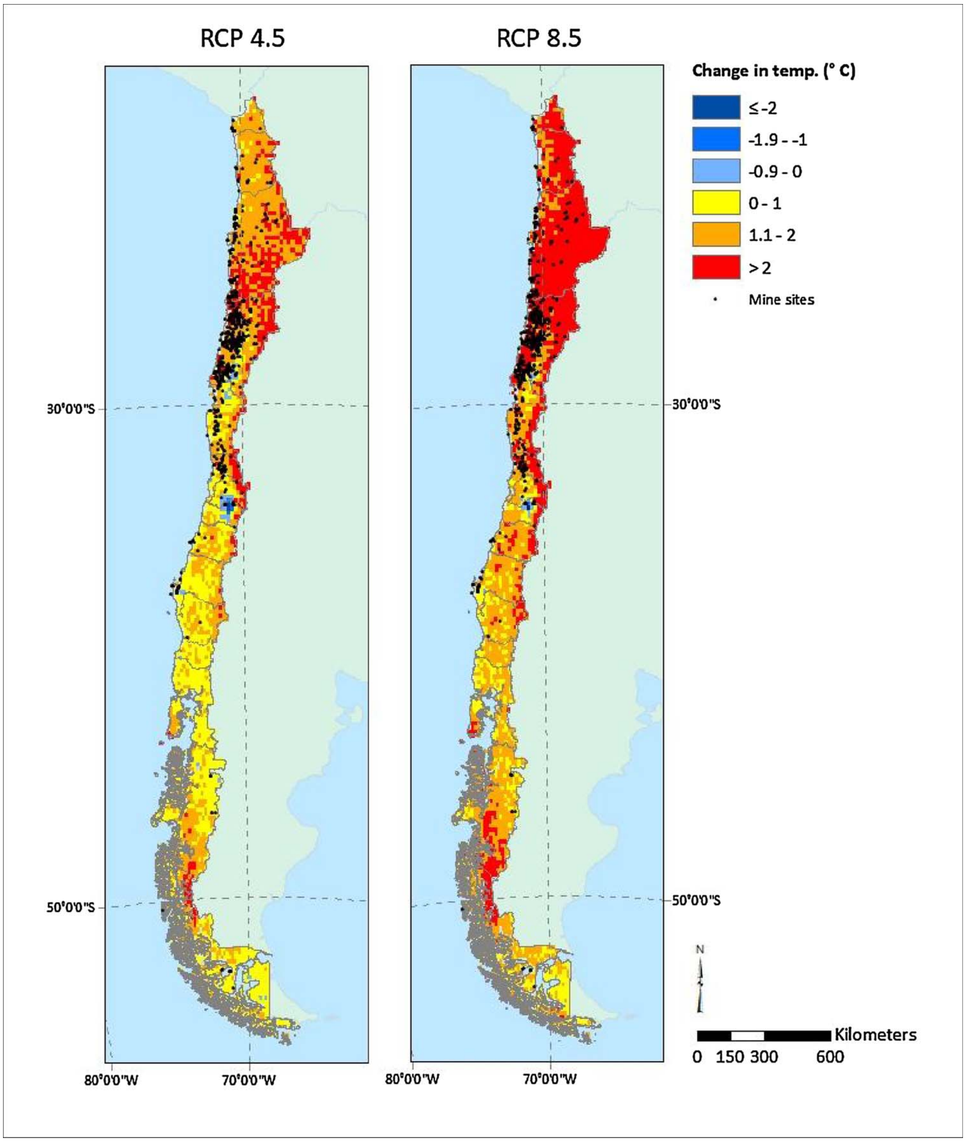

Fig. 1. Mine sites and projected change in average annual temperature in Chile by 2050. Maps represent the projected change in average annual temperature from current levels (1970–2000) to 2050. Annual levels are calculated by taking the average of each monthly maximum and minimum temperature, summing them, and dividing by twelve. Projections employ CMIP5 data, specifically the HadGEM2-ES GCM. Mine sites represent small, medium, and large-scale subterranean and open pit mines in operation in 2011 or 2012, depending on the data source. See endnote 4 for a complete listing of data sources.

The IPCC's AR5 (Magrin et al., 2014: 1517–18) highlights a number of studies that have already observed substantial hydrological changes in the latitudes associated with the Andes of Central and Southern Chile (31–55°S),[5] including declines in glacial volume and area and changes to runoff. Declines in glacial volume are also evident for the "Desert Andes" between 17 and 31°S. Looking to the future, the report projects substantial decreases in runoff to rivers in the middle of the country, specifically noting vulnerability in the Santiago area (pp. 1519–21)—a region expected to see growth in copper mining.

These simple representations of the spatial relationship between mining and climate change in Chile (Figs. 1–3) suggest the potential for substantial climate change impacts on mining operations there over the next three decades. Not dissimilar patterns might be expected to emerge in other arid and semi-arid regions with high levels of mining intensity and water scarcity, such as northern Mexico, the Southwest United States, Peru, southern Africa, and western Australia (Bury et al., 2013; ICMM, 2013). The most important conclusion from this analysis for the purposes of this paper, however, is simply that the impacts of climate change are projected to intersect directly with mining regions, suggesting the need for further analysis of how this will occur, where, and what will be its impacts. The conceptual framework proposed in the following section is intended to provide a structure to facilitate research and collaboration on these topics moving forward.

III. Conceptual framework

It is not our objective in this paper to build a *theory* of the relationships between climate change and mining.[6] Instead, we propose a simple framework that identifies the principal types of nature-society relationship at stake in the interactions between a changing climate and mining. The purpose of the framework is to help organize the literature that exists, and to suggest—through an emphasis on particular types of causal relationships—where future research might be focused. Within the limits of this paper, there is not space to apply the framework to a particular country context, though this is a further way in which the framework might be used.

In the spirit of simplicity, the framework (Fig. 4) is based on a small number of domains: "climate change," "mining activity," "public policy and industry practice," "intersecting impacts," "perceptions and

[5] The studies include analyses of both Chile and Argentina at these latitudes.

[6] See Loginova and Batterbury (2017) and Bebbington et al. (2015) for attempts at such an exercise, the first based on the resilience literature and the latter based on the political settlements literature.

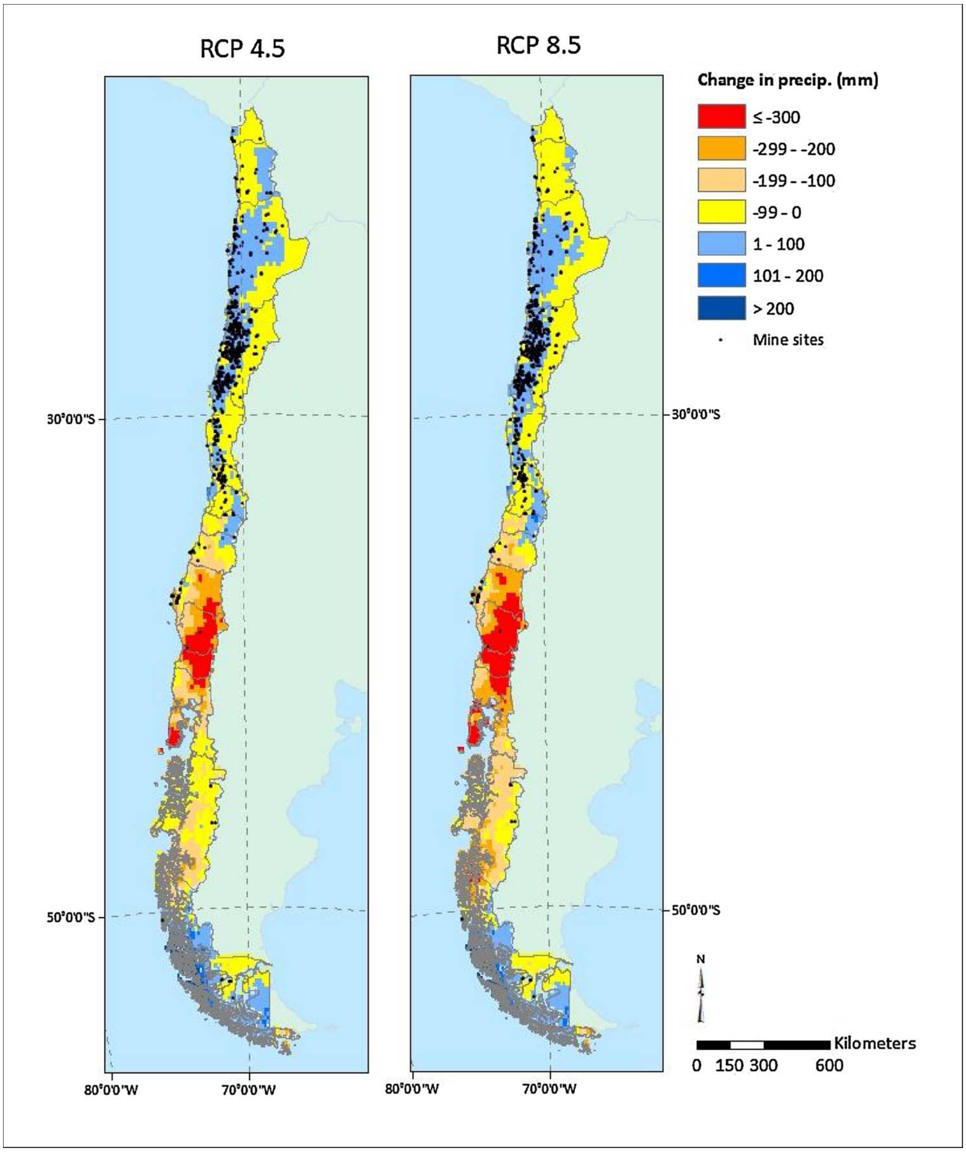

Fig. 2. Mine sites and projected change in average annual precipitation in Chile by 2050. Maps represent the projected change in average annual precipitation from current levels (1970–2000) to 2050. Annual levels are calculated by summing the average monthly precipitation levels. Projections employ CMIP5 data, specifically the HadGEM2-ES GCM. Mine sites represent small, medium, and large-scale subterranean and open pit mines in operation in 2011 or 2012, depending on the data source. See endnote 4 for a complete listing of data sources.

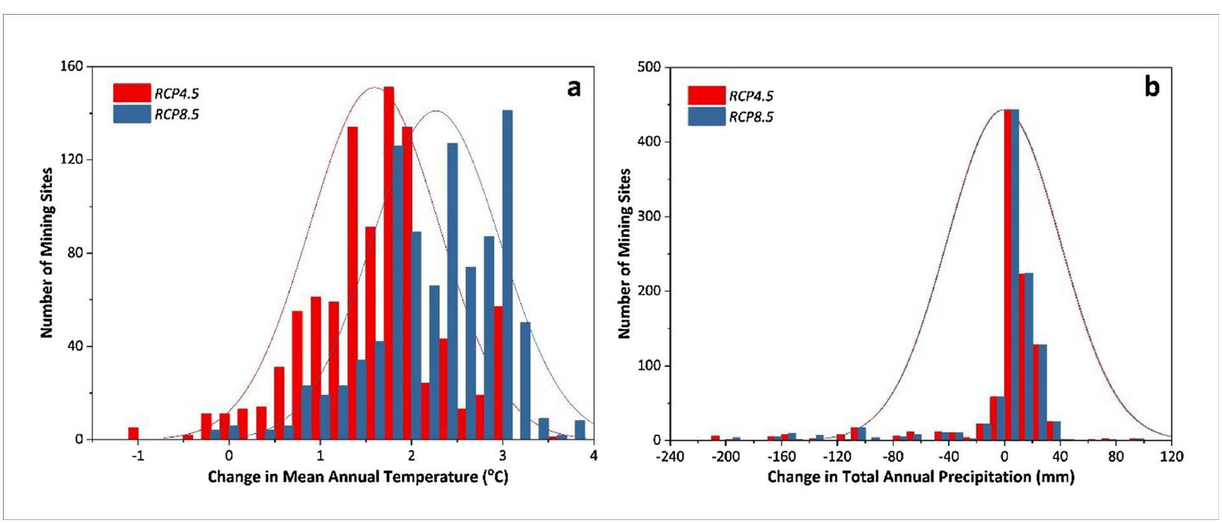

Fig. 3. Number of mining sites in Chile projected to experience a given change in mean annual temperature (a) and annual precipitation (b), by 2050. Data derived from Figs. 1 and 2.

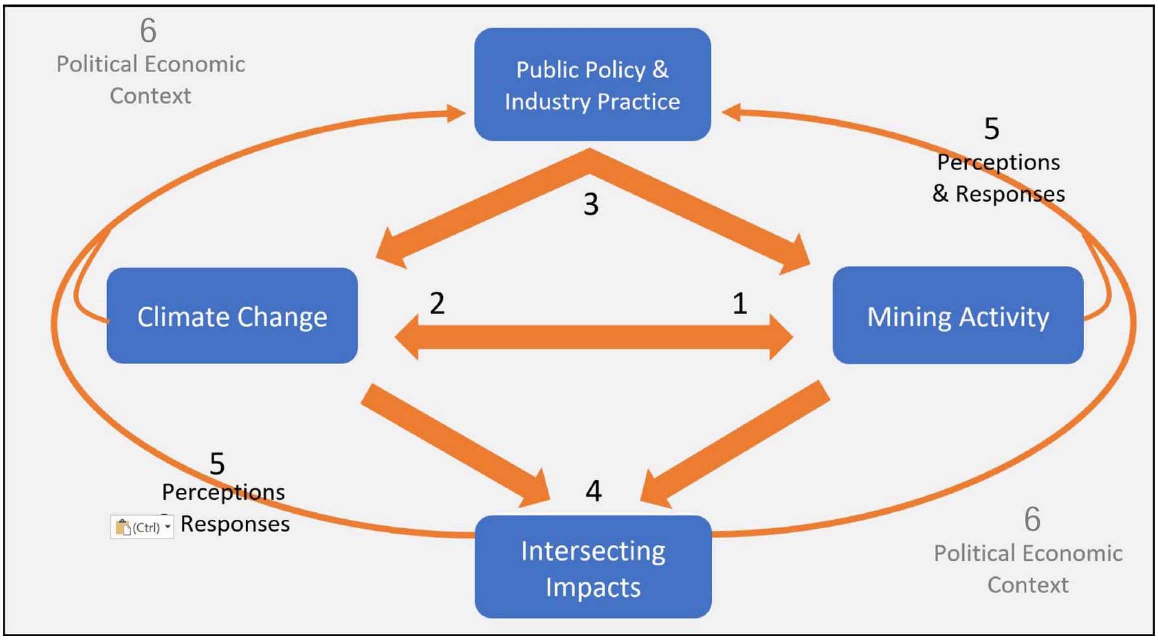

Fig. 4. Conceptual framework of the categories of relationships between climate change and mining. The point labelled "1" represents a relationship in which climate change directly affects mining activity, while in 2, mining activity contributes directly to climate change. The point labelled 3 represents relationships in which public policy or industry practice affect both mining and climate change. In 4, mining and climate change result in intersecting impacts on the same social or environmental factors. In 5, Relationships 1, 2, and/or 4 affect perceptions and responses of civil society, industry, and government actors that in turn affect public policy and industry practice (Relationship 3), creating a positive feedback loop. Finally, this cycle takes place within specific political economic contexts (6)—for example, modernist economic development regimes—that affect the nature of each type of relationship.

responses," and "political economic context." It hinges around a parsimonious reading of the relationships among these domains. At the center of the framework is the direct relationship between climate change and mining activity. Much of the research that does exist focuses on this relationship—identifying interactions between the two, or, more frequently, speculating on what those interactions may look like in the future as climates change more profoundly. This literature focuses almost entirely on large-scale mining, though in our framework, "mining activity" can just as easily refer to ASM. In simple terms, this two-way interaction draws attention to:

1. *The impacts of climate change on mining activity*. Examples of this might be increasing water scarcity that complicates production and processing activities at the mine (and may ultimately lead to mine closure, mine redesign, or technological change[7]); climate warming that leads to ice melt that opens access to previously inaccessible mineral deposits; or permafrost melt that complicates mine access and infrastructural stability.
2. *The impacts of mining activity on climate change*. Examples of this may include cases where: the expansion of both ASM and large-scale mining in forested areas leads to the release of greenhouse gases due to forest clearance and loss; coal mining brings geologically stored carbon to the surface for release into the atmosphere; and more generally, greenhouse gases are emitted by mines and the mineral value chain.

The domains of "intersecting impacts" and "public policy and industry practice" point to ways in which climate change and mining come together in broader social processes:

3. *Public policies and industry practices affect both mining activities and climate change directly*. For instance, land use zoning policy, or tax policy, can affect the scope and geography of both mining activities and greenhouse gas emissions. Similarly, mining industry practices affect choices about mine site environmental performance, as well as the levels of greenhouse gas emissions and carbon offset regimes linked to the mine site.
4. *"Intersecting impacts."* This concept draws attention to the many ways in which the impacts of climate change and mining interact with each other to produce qualitatively or quantitatively distinct types of impact. Water is again a clear illustration of this, as, for instance, in those cases where climate change leads to reduced water availability and then mining activity further reduces water availability for non-mining users. In this case, a further interacting impact might be social conflict or the displacement of livelihoods, each aggravated by water insecurities driven by climate change and mining activities.

The final two domains draw attention to processes that affect both the nature of these prior four domains and how they interact with each other.

5. *Perceptions and Responses*. This refers to the ways in which learning processes influence how society, state, and industry act in the face of climate change and mining and the ways in which they interact. There is much at play here, and for both "perception" *and* "response" there is the question of whether and how climate change, mining activity, and their "intersecting impacts" will be perceived, and also whether and how actors will respond on the basis of these perceptions. This focus on perception and response draws attention to the sorts of policy processes addressed in much writing in sustainability science (Clark et al., 2016).
6. *Political economic context*. This component of the framework recognizes that the other domains and interactions exist within a broader political economy. On the one hand, these interactions influence the political economy (and this is even more the case in mining-dependent and/or climatically vulnerable economies), while the political economy also influences the nature of mining, the drivers of climate change, how the two interact, and how public,

[7] Though in the terms of our framework, such subsequent management or policy changes on the mine site are an example of change in "public policy and industry practice" triggered by perceptions of the impacts and implications of climate change.

civil society, and corporate actors respond to these interactions.

In the following section, we first consider the validity of this framework by relating it to a focused, structured review of the literature, and identify potential patterns within our results. We then draw upon the framework to carry out a more extensive review of existing research.

IV. What does the literature say about mining and climate change?

In this section, we conduct a review of climate change in two parts. In the first subsection, we perform an initial literature review to assess how far the framework proposed in the previous section captures the main relationships of concern in the literature, and conduct a preliminary analysis of patterns that emerge from this review. This forms the foundation of a broader and more detailed analysis of existing academic and policy literature contained in Subsection B.

A. Overall patterns in the literature

This initial review follows a systematic but tightly focused procedure. We were interested in identifying literature that was clearly and explicitly concerned with the relationships between mining and climate change; we did not search for literature that had other objectives but commented on climate change-mining relationships in a way that was subsidiary to its main concerns. In a similar vein, we did not assess the ancillary comments on climate change in literature that had a different focus, even when that focus might be relevant to the climate change-mining relationships (e.g. research on water). We made these choices not because we are critical of these literatures, or do not believe that the literature on water in mining districts is not relevant to climate change discussions. Rather, our concern was to assess the extent to which there is a clear field of work on mining and climate change (in the way that there is, for instance, a clear field of research on mining and social conflict). We took this focus because it is our sense that the field is still underdeveloped, and that this is a problem because it is increasingly important for there to be a consolidated literature on mining and climate change in order to inform public and private decisions on the future of mining and on climate change mitigation and adaptation in mining areas.

With these points of departure, we searched Harvard University[8] Library's HOLLIS+ database for articles that were tagged as peer-reviewed by the database, and whose titles contained *both* a derivative of the word mining, *and* the terms climate change or global warming. Specifically, we used the following search command:

> (mining OR mine OR mines OR miner OR miners OR mineral OR minerals) AND ("climate change" OR "global warming").

This search returned 121 results, of which 28 were relevant to the topic at hand. These articles are marked with asterisks (*) in the References.[9] We then coded the articles into the categories of our framework, based on the key topics they addressed. Four articles were coded as addressing two categories, and the rest as addressing only one (no article was coded as addressing none of the relationships in the framework). Fig. 5 shows the results of this coding, by category of the framework. The articles show a relatively even distribution among the different categories, with the exception of Category 2 (the direct contributions of mining to climate change) which was addressed by only two of the articles.

Two other patterns in the articles identified merit note. Fig. 6 breaks down the articles by year published. The first article explicitly addressing mining and climate change in its title was published in 1998, with the second article only being published in 2005. This reflects the recent and still underdeveloped nature of this field of enquiry. Finally, Fig. 7[10] presents the articles by their country of focus. Of the 28 articles, five did not consider a specific region, and one included discussion of three countries. In addition, one article covered dynamics across the whole of the Arctic and so is not displayed on this map, as no single country can represent this region. While the map is based on far too small a number of publications on which to draw any conclusions, two patterns are of note. First is the emphasis on Australia and Canada, which may reflect the significance of the extractive economy to these countries, the two countries' more significantly developed national research capacity on their domestic mining sectors, and researchers' and the sector's self-awareness of the relevance of climate change to their domestic mining sectors (with water shortages and intense temperatures being especially relevant in Australia, and thawing of ice and permafrost being issues in Canada).[11] Second is the relative lack of research that explicitly addresses mining and climate change outside of Organisation for Economic Co-operation and Development (OECD) and BRICS (Brazil, Russia, India, China, and South Africa) member

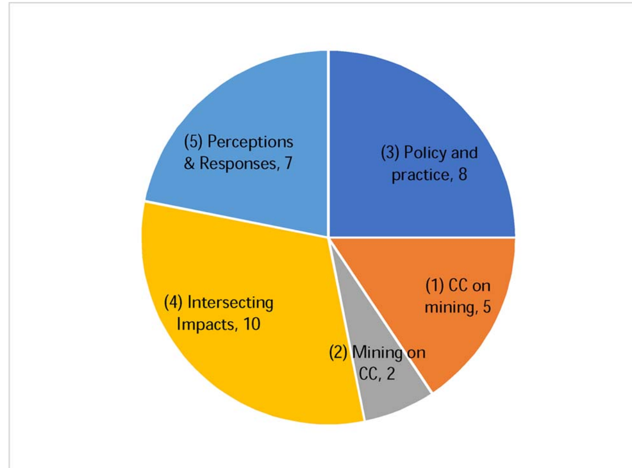

Fig. 5. Number of articles identified, by type of framework relationship. Note that the total number of cases categorized in this chart is 32, as four of the 28 articles were coded into two categories.

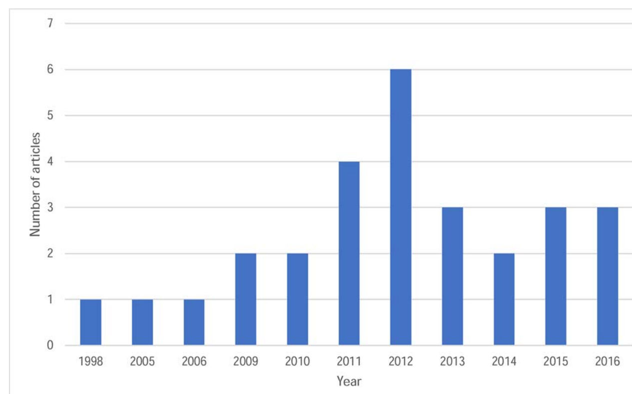

Fig. 6. Number of articles identified, by year.

[8] Where the first author had an affiliation as a Resident Tutor.

[9] Non-English articles were excluded. This was a difficult decision, not least given our own work in Latin America and Siberia and the fact that we ourselves also publish in languages other than English. However, ultimately the decision was driven by the notion that shared fields of enquiry are created in a common language, and at an international level, this is English. It therefore remains possible (though we suspect unlikely) that there are vibrant communities analyzing mining and climate change only in other languages.

[10] Data source for base map of global country boundaries in Fig. 7: "DIVA-GIS," 2011.

[11] It may also reflect the search for only English-language sources.

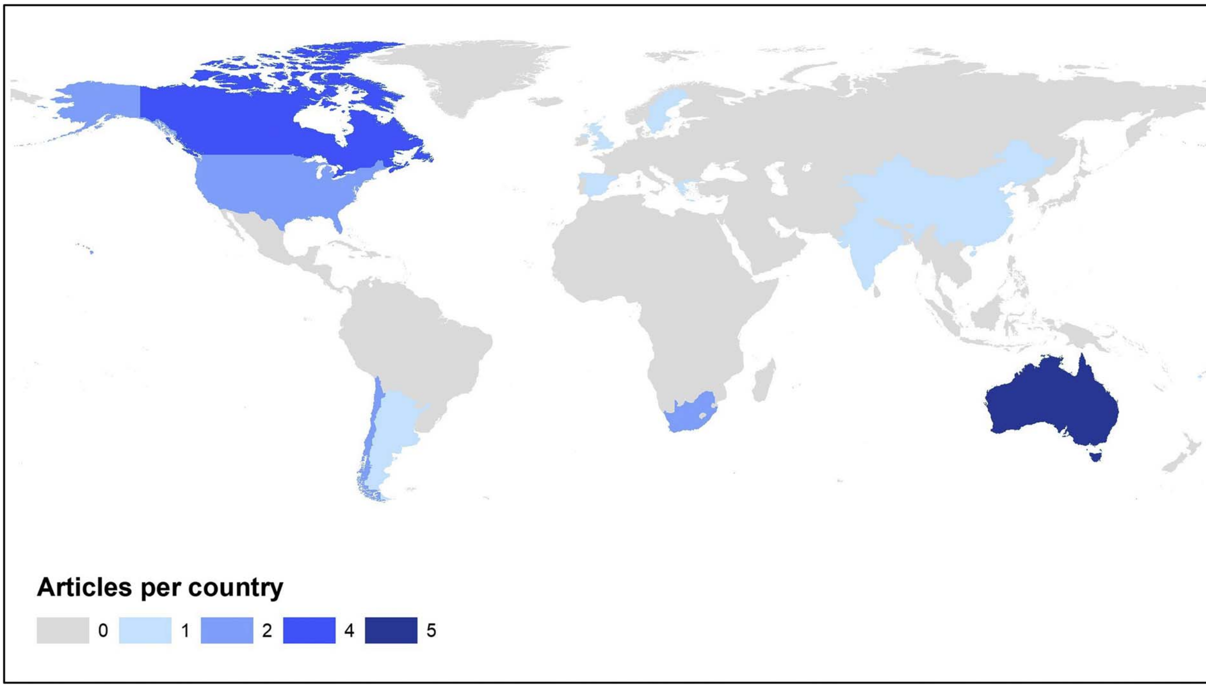

Fig. 7. Number of articles identified, by country of focus. This map draws attention to the lack of research on developing countries. Note that of the 28 total articles identified, six were not associated with a specific country, but one discussed three countries. Thus, 24 cases are presented in this figure. See footnote [10] for the data source of the base map.

countries. This is particularly noteworthy given the dramatic expansion of mining operations in these other economies,[12] and given that the impacts of climate change are expected to be most severe in developing countries (IPCC, 2014a).

Overall, the patterns noted above suggest that: 1) our framework is helpful for describing the structure of research on the relationships between climate change and mining; 2) there is a lack of research on the impacts of mining on climate change, relative to the other relationships highlighted in our framework; 3) most literature on climate change and mining has emerged since 2011; and 4) there is considerable geographical unevenness in the literature on how interactions between climate change and mining are playing out, with a clear absence of research in developing countries. This last point is a particular problem, as it means that there is no evidence base that can be mobilized as part of policy discussions on the advisability or not of encouraging mining in these countries. The possibility for evidence-based policy is therefore severely circumscribed, with debate being limited to (and therefore too easily dismissed as) speculation regarding these relationships.

B. Discussing key relationships addressed in the literature

In this subsection, we discuss in more detail the articles identified in the search described in the previous subsection. We complement the articles identified there with literature published outside of formal academic venues but by bodies clearly concerned with the climate change-mining relationship. We also draw on other relevant academic literature closely related to our topic. These additional references were identified from broader literature and internet searches on the topic. As we discuss this literature, our concern is to identify what is, and is not, being asked in current research programs around climate change and mining. We organize the discussion around the five key relationships identified in Fig. 4.

[12] For instance, 43% of mining investment in 2011 went to Latin America and Africa (ICMM, 2012b).

1. Relationship 1: Climate change affects mining

Existing literature that falls within this relationship has focused on two ways in which climate change may affect mining. The first, which receives more attention, has to do with the ways in which climate change creates new vulnerabilities for mining operations and so demands adaptation strategies on the part of the sector. The second is that climate change may enable access by mining operations to resources that were previously inaccessible. We discuss each in turn.

a. Mining operations are vulnerable to climate change

Citing Ford et al. (2010, 2011) and Pearce et al. (2011), the IPCC's AR5 (Arent et al., 2014: 676) notes the high level of vulnerability of the mining industry to climate change, particularly because mining facilities were built assuming a stable climate:

> Climate change will affect exploration, extraction, production, and shipping in the mining and quarrying industry (Pearce et al., 2011). An increase in climate-related hazards (such as forest fires, flooding, windstorm) affects the viability of mining operations and potentially increases operating, transportation, and decommissioning costs. Most infrastructure was built based on presumption of a stable climate, and is thus not adapted to climate change (Ford et al., 2010, 2011; Pearce et al., 2011).

Investigating specific cases, Pearce et al. (2011) and Damigos (2012) examined the impact of climate change on the Canadian and Greek mining sectors, respectively. Through interviews conducted in five case studies, Pearce et al. determined that climatic changes are already affecting mining operations, but that companies are not prepared to adapt to the challenges that this brings, and in general, are not concerned about the issue. For his part, Damigos conducted a simulation to estimate the costs of climate changes to the Greek mining sector, concluding that these could come to US$ 800 million by 2050 owing to climate change impacts such as decreased water supply, destruction of equipment in extreme weather events, and loss of productive labor hours due to an increase in high-heat days. Necessary adaptation measures, however, would cost only US$ 312 million, suggesting a

financial incentive to invest in adaptation.

In his literature review of climate change and mining, Phillips (2016) investigated five interactions between the two. Most of these fall into Relationship 4 of our paradigm, as they focused on the ways in which climate change and mining interact to affect outside factors (such as air and water pollution). However, he also made two points that highlight how climate change affects mining. First, climate change will alter hydrological processes, with two types of impacts on mining: flooding of coastal operations in the event of sea level rise,and increasing water scarcity in mining regions, which would make operations more difficult and lead to conflict with other local water consumers. Second, he argued that climate changes could increase the likelihood of spontaneous mass movement of rock material (such as landslides), which can be triggered by weather events. This increases risks to the slippage of waste rock, the failure of tailings dams, or more general earth movements in mining areas. Indeed, in the debates in El Salvador discussed in the introduction, one of the areas of concern was the increased risk to tailing dam stability that would arise from the already documented increase in frequency of high magnitude storms and hurricanes (Bebbington et al., 2015).

The potential for adverse effects of climate change on mining has also occupied public sector research. A series of reports from CSIRO in Australia has addressed this issue. Hodgkinson et al. (2010) noted that increased temperatures at Australian mine sites may complicate mines' "ability to source staff, to ensure health and safety for workers within the mine site, to ensure that production can continue at projected rates and to maintain the industry's strength into the future" (p. 3). More generally, they concluded that "most stages of mining … are already influenced by climate and extremes" but that "the production stage is likely to be the stage that is most at risk from climatic events and climate change in the future" (p. 3). They noted risks to water and energy availability, including the possibility that power supplies might be lost owing to high magnitude events. They suggested that increased automation of mine operations might be a response to these hazards, as well as water-saving technology. Speaking, however, to relationships of perception and responses (see below), as well as political economy constraints, they commented that "some experts have suggested that there may be some resistance to adaptation requirements due to short-term financial constraints and the notion that climate and weather variability may not be a real threat" (p.4). A study by Australia's National Climate Change Adaptation Research Facility (Mason et al., 2013) documented a similar set of climate change risks to Australia's mining industry: flooding and storms, drought, and high temperatures. The authors noted that these imply both increased operating costs and risks to the mining industry, and demand adaptation. Indeed, the economic costs to mining are already high: the 2010–11 Queensland floods are estimated to have led to losses to the mining industry of AUS$ 2500 million (citing Easdown, 2011).

b. Climate change could open new areas to mining

Mager (2009) argued that extractive operations could expand dramatically in the Arctic in coming years. He based his assertion on the interaction of two key drivers: the sustained commodity price boom beginning in the early 2000 s that increased the feasibility of exploration in previously unprofitable areas (owing to the expense of accessing the resources); and the melting of Arctic sea ice opening access to previously inaccessible territories and transportation routes, through which mining operations could access new resource deposits. He argued that international structures must be put in place to mediate potential conflict over these resources and access routes (see also Jenisch, 2012, and Section IV-B-5 below). While subsequent falls in mineral prices may have slowed this expansion, the move among Arctic countries to make claims on the sea bed has not stopped, and it seems likely that the melting of sea ice has already changed ideas about future resource frontiers in the industry.

An important case for examination of this trend is Greenland, which has been embroiled in heated debate in recent years over the future of its rich mineral deposits (Committee, 2014; Nuttall, 2012; Rosen, 2016). Though politically independent from Denmark since 2009, the Arctic nation remains economically dependent upon its former colonial power (Rosen, 2016). Yet the country "has excellent potential for iron ore, copper, zinc, gold, uranium, and light and heavy rare earth elements" (Boersma and Foley, 2014: VII), and the government intends to exploit this mineral wealth (along with offshore oil) to achieve more complete independence. This has been accompanied by a "fourfold rise in the number of exploration licenses from 2003 to 2013" (Committee, 2014: 12). Boersma and Foley (2014) note that climate change has made recent exploration efforts possible by improving access to the Arctic region. At the same time, a report of the Committee (2014), of the Universities of Greenland and Copenhagen, argues that climate change has "had a marginal impact on … interest" in Greenland's mineral wealth (p. 12), instead pointing to attractions of the country itself, such as its "size, geological structure and high level of basic geological and geophysical data" (p. 12). Perhaps more important, however—and in line with Mager's argument summarized above—is that Greenland's interest in extraction coincided with the boom in commodity prices (Boersma and Foley, 2014) that, since 2011, has begun to decline (Rosen, 2016; International Monetary Fund, 2016). The example of Greenland thus indicates that climate change may enable access to previously unexplored minerals, but that major extraction operations are only likely if mineral prices justify them financially and geological conditions permit them.

Related to the potential for geographical expansion of mining operations due to climate change is the possible extraction of new types of minerals. Lai et al. (2005) argued that mining deposits of methane hydrate within the continental shelf might provide an alternative source of energy that would release fewer GHGs into the atmosphere than traditional sources. The broader point is that climate change mitigation efforts are likely to lead to the extraction of different fuel sources (particularly in place of coal), as well as different metals used to produce renewable energy infrastructure, such as the rare earth minerals discussed above, as well as minerals such as copper (Ali et al., 2017; Switzer et al., 2015). Though not strictly "mining," an important variant of this phenomenon is the way in which climate change has driven increased demand for natural gas as part of national strategies to reduce emissions. This in turn has opened new areas to potential resource extraction, as the fracking frontier expands rapidly. The last decade has seen the identification of extensive potential fracking regions across Latin America. Brazil, Mexico, and Argentina have particularly high levels of gas, with Argentina possessing more than both the United States and Canada (Bailey and Viscidi, 2016). The expansion of fracking in the US is an example of adaptation to climate change (coupled with technological change) driving the expansion of another resource frontier. At the same time, Bailey and Viscidi (2016) noted that "Shale wells can release some 230 times more natural gas and volatile organic compounds…than standard wells" (p. 5). This is particularly concerning if methane is leaked, as it is a more potent greenhouse gas than carbon dioxide, and thus contributes further to climate change.

Key conclusions gleaned from the literature in this category thus include: 1) Climate change will impose substantial economic costs on mining operations, and these have already been observed at Australian and Canadian sites; 2) Climate change will open up access to natural resources that were previously inaccessible, potentially leading to an expansion of mining operations; and 3) Climate change is likely to lead to a substitution of mined resources currently in high demand by other resources, either for fuel or to be used for the production of energy-efficient infrastructure.

2. Relationship 2: Mining contributes to climate change

In an article that grew out of a broader review of the sustainability of Australian mining, Mudd (2010: 114) comments that mining's contributions to "greenhouse emissions and climate change" are "one of the most fundamental challenges to the environmental sustainability of the mining industry in Australia." This is not only because of the place of coal in the country's mining sector, but also because of the threat posed by declining ore grades and ever deeper pits in a mature mining economy. Extracting the same amount of mineral out of a poorer grade of ore requires the use of more water and more energy, increasing emissions, and pressure on water resources (Chilean mines face similar challenges). Industry publications have expressed similar concerns to Mudd's (ICMM, 2009, 2012a). Discussing the case of Australia, Hodgkinson et al. (2010: 3) note that "[c]limate change research and activities in the mining and exploration industry typically focus on what can be done to reduce mining's impact on climate change."

As these latter citations suggestion, much of the work on the topic of mining's contributions to climate change would appear to be conducted by the industry and associated government and private sector centers of research and innovation. Indeed, in our review of journal publications *explicitly* speaking to the relationship between mining and climate change above, only two articles[13] addressed the direct contributions of mining to climate change. These two articles also discussed policy drivers, and so will be discussed further in the following sub-section (Christensen et al., 2011; Irarrázabal, 2006). Christensen et al. are critical of Australia's heavy use of coal, given its contributions to climate change. Irarrázabal (2006) gives a more detailed analysis of the sources of GHGs within mining operations. First, he distinguishes between direct emissions—such as the carbon dioxide released by a truck hauling rock at a mine—and indirect emissions—such as the electricity generated at a coal fired power plant that provides energy to the mine (see Mudd, 2010, also). He goes on to distinguish between two types of direct emissions—those used in processing mined material, and those used to extract the material. He states that the latter produce higher emissions than the former, as two-thirds of fuel used in the extraction phase are fossil-based.

The nature of this relationship between climate change and mining begs the question of how much carbon dioxide or other greenhouse gases the mining industry emits at the global level. Though noting the tenuous nature of data on this topic, Irarrázabal (2006) offered estimates only for Canada and the USA, either by calculating emissions for specific companies or by using levels of energy use as a partial proxy for emissions. Calculations by the ICMM (2012a) give a clearer global estimate, suggesting that the mining and metals industry contributes approximately 2% of global GHG emissions—"[a]pproximately half … from fuel use in mining and processing operations, for transportation of ore and electricity generation at remote sites and from fugitive emissions…", and "… half from electricity use, primarily in refining and smelting operations…" (p. 2). Emissions from this source are not, therefore, as significant as those from others such as agriculture, forestry, and other land use (AFOLU); transport; and buildings (IPCC, 2014b: 9). They are, though, not insignificant, and present a challenge to the industry to reduce emissions—not only in order to be climatically responsible, but also as a legitimacy-enhancing exercise vis-à-vis the public and financial capital increasingly concerned with climate risk to investment.

3. Relationship 3: Public policy and industry practice affect both climate change and mining

The concept behind this relationship is that both industry practice and national and international public policy affect climate change and mining activity, and can often affect both at the same time. For example, a policy intended to reduce carbon emissions may force mining companies to scale back their energy use. Conversely, a policy to promote the coal industry (as in contemporary Indonesia or the US) can also have the effect of increasing GHG emissions. Our survey of the peer-reviewed literature identified articles addressing such relationships in Australia, Chile, China, South Africa, and the United States.

a. National Policies

Christensen et al. (2011) and Muenstermann (2012) criticize Australian policies that promote coal as a source of domestic energy supplies and a driver of economic growth. Indeed, coal is the country's main export commodity and primary source of domestic energy. Both articles draw attention to coal mining's direct and indirect contributions to climate change: through the emissions of mining operations themselves, and through the burning of coal. In part because of this, according to Muenstermann, "Australians are the largest emitters of greenhouse gases per capita in the developed world" (p. 231). Christensen et al. criticize policymakers for not effectively using existing policy structures to regulate coal extraction and emissions. They assert that policymakers continue to approve coal mining projects, with little oversight, because the economic benefits are much easier to predict than are the climatic impacts. Moving forward, they call on policymakers to use their regulatory capacity to ensure a reduction of emissions from coal mining operations.

National policies that promote less carbon-intensive forms of energy can also have implications for mining. The promotion of natural gas, for instance, can have the joint effect of expanding extractive frontiers in areas of gas deposits, while rendering coal mining less competitive because of the relative cheapness of natural gas. In a variant of this relationship between existing geographies of mining and the opening of new frontiers for renewable energy, Muenstermann (2012) pushes back against opposition to the development of wind energy production as an alternative to coal-powered electricity in Australia, and suggests that the coal industry is involved in the effort to block the adoption of renewables.

It is worth noting that while the peer-reviewed journal literature on these issues appears limited, there is significant activist and environmental justice work around such relationships. While much of this focuses on oil (and keeping it in the ground), coal also attracts much attention and applied research (e.g. FERN, 2015). The US is one focus in this work, as also are Indonesia, South Africa, India, and China. While for reasons of domestic advocacy this work often focuses on the adverse impacts of coal mining on human health and water courses, it also draws attention to the ways in which national policies to support coal are aggravators of climate change, and so threaten to undermine countries' Intended Nationally Determined Contributions (INDCs) to reduce GHG emissions, under the United Nations Framework Convention on Climate Change (UNFCCC). Another focus has been on the effects of pig iron production on forest loss (e.g. in Brazil) because of the use of charcoal in pig iron production. The relative lack of peer-reviewed work on coal policy suggests that academic debate is lagging behind knowledge production in civil society.

b. International Policy

The earliest article encountered in our search was Barrett (1998), written shortly after the United States signed the Kyoto Protocol of the UNFCCC to reduce global emissions. Though the United States never ratified the treaty, at the time that Barrett wrote, it appeared likely that the country would adopt a cap and trade system to reduce carbon emissions in compliance with the treaty. Barrett argued that such a scheme would inevitably lead to layoffs, especially within the coal

[13] Though we only found two articles coded for this particular relationship in our review of peer-reviewed publications, it is important to note that other authors (e.g. Hodgkinson et al., 2010) have suggested that the industry is focused primarily on mitigating the impacts of climate change (such as through reducing GHGs), but perhaps not enough on adapting to the climate changes that will affect mining operations and surrounding areas directly.

mining industry of the Appalachian region. He thus urged policymakers to sell the emissions credits of the cap and trade program (rather than give them away, as would be more politically welcome) so that the resulting funds could be used to finance adjustment benefits to the unemployed. Among the articles in this literature review, this one is unique in its discussion of the labor effects of the relationship between climate change and mining. Yet this relationship remains acutely relevant, as reflected in current domestic political debates on the implications of climate change policy for coal workers in the contemporary US and Australia. Irarrázabal (2006) similarly pointed out that the mining industry will have to adapt to climate change, in part because international climate policies like the Kyoto Protocol will make mining operations more expensive.

The ways in which policy affects the relationships between mining and climate change go well beyond debates around coal. Switzer et al. (2015) described a case in which China restricted its exports of rare earth minerals due to ostensible environmental and health concerns. Given that these minerals are necessary for the production of renewable energy technologies, several countries responded by protesting the action through the World Trade Organization's (WTO) Dispute Settlement Mechanism (DSM). China argued that under Article XX of the General Agreement on Tariffs and Trade (GATT)—the precursor to the WTO—countries were allowed to defy normal trade rules in the defense of health and the environment. In a complicated decision, the WTO denied China's appeal for exception and ruled in favor of the complainants. The authors worried that this ruling indicates that the WTO is incapable of adequately responding to concerns over the environmental and human impacts of mining, while at the same time ensuring the production of renewable resources needed to combat climate change. This complex case demonstrates clearly how international agreements and laws can affect climate change and mining, both directly and indirectly.

c. Industry Practice

Three authors addressed the topic of industry practice from quite different angles. In a piece of quite applied research, Ostojic (2015) introduced a new pump developed in Chile that could be used by mining operations to improve energy efficiency and reduce carbon emissions. Mzenda and de Jongh (2011) conducted an analysis of the South African mining industry, concluding that it is unprepared to respond to the changing business environment that climate change will create. Finally, Pellegrino and Lodhia (2012) employed "legitimacy theory" to investigate how mining companies positioned themselves during Australia's debate over the implementation of an emissions trading program. Through analysis of two individual companies and two industry groups representing multiple companies, they concluded that the mining industry perceived a threat from climate change and used its public relations platforms to help ensure social license to operate. The mining companies and industry groups performed an implicit division of labor to do so. Mining companies focused on strategies such as educating stakeholders about their efforts to respond to climate change and improving perceptions of their practices. They did not, however, place much emphasis on changing expectations of behavior by the mining industry—a legitimation strategy which instead received heavy focus from the industry groups. The authors argued that this was in part due to differences in audience, with the companies addressing groups ranging from employees to environmental organizations, while the industry groups, through lobbying, primarily addressed policymakers

The articles that addressed how public policy and industry practice influence climate change, mining activity, and the relationships between them also point to the ways in which these relationships are embedded in, and affected by, broader political economies. Broader political and electoral calculations, relationships of power, the constraints of capitalist accumulation, and geopolitical maneuvers each affect policy and corporate responses. Thus, the protection or expansion of coal production can also be driven by efforts to secure miners' votes, by the lobbying and corporate power of coal companies, as well as by policy concerns to widen energy access to poor communities (as in Indonesia or South Africa, for instance). Policies promoting coal may also be driven by populist commitments to forms of resource nationalism on which the legitimacy of national leadership partly depends (e.g. the US and India). China's maneuvers around exporting rare earths were presumably also motivated by efforts to protect its domestic clean energy technology sector and to exercise geopolitical power. And, to return to the example in our introduction, the government of El Salvador held off any ban on mining until they were certain it would not imperil an investment dispute with the Pacific Rim mining company that would have cost the country over US$ 300 million had they lost (Bebbington, 2015; Bebbington et al., 2015). Even then, the conservative voting bloc in the National Assembly appeared to support the ban mostly because of an electoral calculus that they would lose voter support should they oppose it. This discussion thus indicates that analyses of the relationship between climate change and mining must incorporate a political economy perspective in order to comprehend both the drivers of climate change and risks to the livelihoods and rights of vulnerable populations. Such a perspective aids in understanding both the constraints to change as well as where incentives can be affected in such a way as to foster more productive public policy and industry practice.

4. Relationship 4: Intersecting Impacts

In our organizing framework, the notion of intersecting impacts encompasses the idea that climate change and mining can interact to affect the same outside factors, *or* that each of them can affect the same factors independently. Simplifying, we parse the literature on this topic into work which addresses intersecting physical and environmental impacts, and that which focuses on intersecting human and social impacts. Given the codependence of human and physical systems, this distinction is merely a framing device, but one that helps organize the literature that exists. Strikingly, of the ten articles coded for this relationship in our focused review in Subsection A above, eight primarily addressed physical impacts. This indicates the need for further research from within the social sciences on the impacts of the relationship between climate change and mining on human societies at different scales. The implication is that while much is claimed in advocacy or policy about the nature of these impacts, far less has been empirically substantiated.

a. Physical systems

Researchers have identified a number of impacts that the interaction between climate change and mining have, or will have, on the environment (many of these impacts also have implications for human systems). Most prominent among these are hydrological impacts. Phillips (2016), Anawar (2013), and Foulds et al. (2014) all raised concerns about the degree to which possible increases in flooding could exacerbate contamination of ecosystems surrounding mine sites. Phillips and Anawar raised specific concerns over increased Acid Mine Drainage (AMD), a process by which metal sulphides become oxidized through contact with water, leading to soil and water contamination, with implications for the health of aquatic and terrestrial ecosystems, as well as of humans. Presumably, AMD would also be accelerated by the locally higher average temperatures likely to accompany climate change. Rayne et al. (2009), raised concerns over water runoff from active and inactive mining sites, and proposed a model to project runoff rates under different climatic scenarios. In addition to these concerns over contamination, Singh et al. (2010) noted that if mines are located below the water table, groundwater can drain into them, reducing available supplies for other needed activities. As already noted, sea

level rise due to climate change could also make some mining sites inoperable, and droughts could lead to conflict with other local water users (Phillips, 2016).

Other scholars raise concerns over the impact of the intersection of climate change and mining on soils. In an experiment in a region of Spain in which soils were contaminated by mining operations, González-Alcaraz et al. (2015) studied the impacts of differing soil temperatures and moisture levels on the survival and reproduction rates of the organism *Enchytraeus crypticus*. They found that though the presence of contaminants and climatic changes did not affect survival, increased temperatures tended to increase reproduction rates, while decreased soil moisture tended to decrease them. In a follow-up study that examined the effects of climatic changes and contaminated soils on *Enchytraeus crypticus* over multiple generations, Barmentlo et al. (2017) found that "…higher air temperature and/or reduced soil moisture content does affect the toxicity of soils polluted by metal/metalloid mining wastes to E. crypticus and this effect may exacerbate over generations" (p. 107). These results indicate that climatic changes will alter how mining affects soil biology. In addition, Hancock et al. (2017) note that in general, plans for mine closure do not adequately take climatic changes—specifically to rainfall—into account, but that changes of this nature can have major impacts on soil erosion.

Finally, Beggs (2012) and De Laender et al. (2012) investigated the effects of climate change and mining on biodiversity. The former points out that a well-documented impact of climate change is the migration of species toward the poles and higher elevations as temperatures increase. Mountain top removal mining, used commonly in the Appalachian region of the United States to extract coal, functions by removing up to 300 m off the top of mountains. As an elevation of 300 m can equate to as much as a 1.95 °C temperature difference, species that have already been pushed to higher elevations due to climate change would find no available habitat at ideal temperatures on mountains affected by this type of mining. For their part, De Laender et al. (2012) found that long-term biodiversity actually increased in the presence of human intervention in a mining site over a 1000-year period, though they suspect that this was due to the emergence of "opportunistic species" that took advantage of human interventions in the landscape, rather than because of any positive benefits of mining related contaminants.

Albeit with some caveats, the balance of scholarship thus indicates that interactions between climate change and mining have negative impacts on a number of environmental factors, including water supplies, soils, ecosystem health, and biodiversity. In most instances, these adverse environmental and physical impacts will in turn affect human systems.

b. Human systems

In the context of this interaction between intersecting physical and human impacts, Edwards (2014) and Birch (2016) focused much more explicitly on the social impacts of mining and climate change. Edwards used a historical analogy which suggests the potential gravity of such joint effects for low-lying islands. She described a case in which a phosphate mine made the South Pacific island of Banaba uninhabitable for its 450 residents. In response, colonial authorities relocated them to the island of Rabi in Fiji in 1945. Arguing that this forced relocation is similar to the impacts that climate change may have on vulnerable island societies, Edwards' article suggests just how grave the combined impacts of both mining and climate change may be in the future. The scenario is not an idle one given the significance of mining for many Pacific island nations. In a similar register, Birch (2016) discussed the experiences of aboriginal communities in Australia that have been adversely impacted by mining operations (especially of coal) and are also particularly vulnerable to climate change.

Cases such as these are instances of what Leichenko and O'Brien (2008) term "double exposure." They argue that when global environmental change and economic globalization intersect, the implications for vulnerable peoples can be particularly severe. Bebbington et al. (2015) used this framework to discuss the drivers of political protest against mining in El Salvador, suggesting that the post-1990s arrival of mining in the country was a manifestation of economic globalization in a society that also ranked among the globe's most vulnerable to climate change. Odell et al. (forthcoming) found similar results in a study in Peru's Apurímac department, where they conducted interviews in seven agricultural communities to investigate factors that contribute to the conservation or loss of native potato varieties. They found that farmers had already observed climatic changes in the region, which they perceived to be negatively affecting their ability to maintain native potato varieties, a crucial component of their livelihoods. At the same time, several respondents also raised concerns over the adverse environmental and economic impacts of the nearby Las Bambas mine, one of the world's largest copper mines, which was nearing construction at the time of interviews. Interviewees noted that the mine had contributed to local inflation, particularly with regard to wage labor, which made it more difficult to hire workers on their farms. Independent of each other, climate change and mining impacts were thus intersecting to place a double squeeze on rural livelihoods.

Across strikingly different geographical settings, then, a key impact of interactions between climate change and mining is the double exposure of vulnerable communities to both economic and environmental hazards. That said, this does not have to be the only outcome. Tax and royalty revenues from mining, assuming they are at the appropriate level, could also be used to invest in climate adaptation infrastructure and strategies in areas affected by mines. How far the presence of mining in areas affected by climate change becomes a source of further vulnerability or one of adaptation depends greatly on political economy questions (fiscal regimes, quality of governance, etc.). Important also are the ways in which mine operators perceive the problem of intersecting impacts and their own potential role in ameliorating climate change effects on populations living in and near mining regions.

5. Relationship 5: Impacts on perceptions and responses

As suggested in the preceding paragraph, how public, private, and civil society actors perceive the ways in which climate change and mining interact with each other, and the consequences of this interaction for environments and societies, is critical to determining how these actors respond through public policy, industry practice, and forms of social protest. The nature of these responses then goes on to influence future interactions between, and impacts of, mining and climate change. Understanding such processes of perception and response is challenging, as it requires access to decision makers, and the sorts of corporate, governmental, and social movement discussions in which perceptions are formed, expressed, and translated into responses. However, there is some literature that sheds light on these processes.

As one example, Kronenberg (2013) compared two different mining proposals to remove glaciers in order to access gold deposits. In the first case, a site in Kumptor, Kyrgyzstan, miners displaced nearly 40 million cubic meters of ice. In the second case, the Pascua-Lama site on the border of Chile and Argentina, miners proposed to move only 800,000 cubic meters of ice. Yet the first case drew little public attention, while the latter became a lightning rod in Chile for local, national, and international protests over the impacts of mining under conditions of climate change (see also Urkidi, 2010). The project was ultimately halted by the Chilean courts in 2013 for environmental reasons. Kronenberg argued that in the Chilean case, the removal of the glaciers became associated among the public with climate change, which had already been threatening glaciers across the length of the Andes. The scenario has also led to a proposed law to protect glaciers within national parks from mining activities. Thus, perceptions of climate change and mining, and the responses of civil society to these perceptions, impacted policies with potential impacts on both climate change and

mining. The comparison also makes clear how political economic context influences these relationships. Chile's democracy allowed for public debate to proceed unrepressed (and also allowed for the open circulation of information and ideas in society), while in Kyrgyzstan this public sphere was much more constrained. Chile's response also reflects a recent Pew Research Center poll (Carle, 2015), which found that respondents in the country—and in many countries of Latin America and the Global South in general—deem climate change to be the greatest global threat.[14]

Research in Canada and Australia has illuminated these processes of perception and response within the industry and the public sector. Ford et al. (2010) surveyed participants at an annual conference for mining company employees, finding that they were concerned about climate change, but were not taking substantial steps to adapt to it. Respondents did, though, report taking steps to mitigate climate change by reducing GHGs from mining operations (a finding consistent with Mudd, 2010; Hodgkinson et al., 2010). In a follow-up re-survey—this time sent to companies across Canada—Ford et al. (2011) confirmed these results, and also found that respondents were not greatly concerned about climate change, but also had relatively low levels of knowledge about it.

Loechel et al. (2013) conducted a similar study in Australia, but targeted both mining employees and local governments affected by mines. They found that mining company employees were less concerned about climate change and less likely to believe that it is occurring. In a follow-up study with a larger sample size, Loechel and Hodgkinson (2014) found similar results to those of their first study, with the key difference that mining company employees were found to be more likely to believe that climate change is occurring than in the previous survey. That said, neither group of interviewees rated climate change as a key priority for their institutions, though local government ranked it more highly than did mining employees.

Three other articles address specific manifestations of the perception/response issue. Muenstermann (2012) argued that erroneous public perceptions of wind energy production have prevented its uptake as an alternative to coal mining in Australia. For their part, Aleke and Nhamo (2016) analyzed the extent to which more substantial use of Information Communication Technologies (ICTs) could help mining companies better adapt to the new business environment created by climate change. They argued that ICTs could help companies prepare for weather emergencies, share indigenous knowledge, and improve company marketing. Finally, Jenisch (2012) raised concerns about the impact of climate change on already tense geopolitical relationships over access to natural resources in the Exclusive Economic Zones (EEZ) of countries defined by the United Nations Convention on the Law of the Sea (UNCLOS). As sea levels rise and new access to continental shelves emerge in the Arctic, conflicts may flare up over who owns the rights to a given set of resources. Jenisch (2012) argued that UNCLOS has many of the tools needed to effectively navigate this challenge, but that additional new international agreements are needed to address it fully.

While disparate, these three articles all emphasize the importance of perception at different levels—whole publics, states and their negotiating teams, and individual companies—in influencing how different actors respond to different intersections of climate change and mining. As we emphasized in the framework, there are of course broader political economy factors that will influence the nature of these perceptions, and if and how they translate into responses. Nonetheless, these studies begin to show the importance of "getting inside" different institutions in order to understand what perceptions exist, how they form, and how they are acted upon. Absent such understanding, recommendations of how to address the intersections of climate change and mining are likely to be unrealistic, and inadequately related to the nature of decision-making processes within different organizations.

[14] This is in contrast to many Western countries, which ranked the Islamic State of Iraq and Syria (ISIS) as a greater concern.

V. Discussion

After establishing in Sections I and II the significance of climate change for mining, and the need for in-depth investigation into this relationship, this paper had three further objectives: 1) to develop and test a framework for organizing literature on the relationships between mining and climate change; 2) to conduct a review of existing literature, identifying overall patterns and discussing it in terms of the framework; and 3) to assess the extent to which there exists a consolidated field of research on mining and climate change, and identify particularly significant gaps in this research field. In this closing discussion, we speak to this final objective.

While the core of our review of the literature used a particularly narrow filter, this strategy enabled us to determine the usefulness of our framework and assess whether this is a substantial and consolidated research field. The answer to this latter question must be "not yet." Important work has been done on different dimensions of the relationships between climate change and mining, but the presence of such work in the journal-based, peer-reviewed literature is still limited. There are important literatures coming from the mining industry, host government research centers, and activist groups (CSIRO in Australia and ICMM stand out among these, along with some civil society groups). Arguably, however, some of this other research lacks the perceived independence that might come from the blind peer review process. But even including these literatures, this is still not a substantial research domain. Much that has been contributed comes as ancillary insights from research whose primary purpose has been different: studies of water resources in the Andes, of forest cover and forest community rights in Indonesia, and so on.

We suggest that this is a serious gap. As climate change proceeds and intensifies, the implications for a range of economic sectors will become more apparent. The energy and water intensity of large-scale mining may make this sector particularly vulnerable. The relative lack of power of resource-poor communities living in areas where such mining is making claims on water and energy resources renders them more vulnerable still. Responses to these vulnerabilities—of the industry, of populations, and of ecosystems—will benefit from evidence-based research. Indeed, in his 2010 article, Mudd implied just how important it was to begin developing an evidence and analytical base when he commented on his own exercise: "These estimates are, by their nature, coarse and are furnished to provoke discussion on what, ultimately, is one of the most fundamental challenges to the environmental sustainability of the mining industry in Australia—greenhouse emissions and climate change" (2010: 114). In essence, Mudd was pointing to the need to generate data, however coarse, in order to begin to have informed debates in the industry, and in society. The more general point is that much more research in this area is needed in order to continue enhancing the quality and accountability of these debates.

If the overall field is underdeveloped, particular parts of it seem all the more urgently in need of elaboration. There is very little literature addressing any of the relationships in our framework for the cases of non-OECD, non-BRICS countries. Yet some of these countries are in particularly vulnerable positions, and face daunting challenges of how to balance the promotion of mining as a means of generating the revenues needed to invest in adaptations to climate change, while also regulating mining so that it does not aggravate socio-environmental vulnerabilities that already exist. While such decisions will be made politically more than analytically, analytical work still has an important role in influencing the ideas, public debates, and accountabilities that will ultimately affect policy choices.

The literature would also be enhanced if there were more examples of how specifically climate change is impacting mining at different spatial scales (local, regional, national), and the particular ways in

which governments and companies are responding. We suggest that the framework presented in this paper might serve to organize such case study analyses by indicating the relationships on which they might focus. The literature would also gain from a far fuller consideration of the relationships between ASM and climate change. To date, scholarly work in this area has been biased towards large-scale mining. Yet the impacts of ASM on forest cover and water in regions such as the Amazon, Indonesia, or West Africa suggests that it too can be an important driver of regional climate change and greenhouse gas emissions, while also having its own particular modes of adapting to the effects of climate change.[15]

A final underdeveloped area relates to the societal implications of the interactions between mining and climate change; more work (though still limited) has been done on the implications for the biophysical environment. Indeed, in the case of El Salvador—to return to where we began this paper—the government had to commission a strategic environmental assessment (SEA) of the mining sector in order to generate some of this data (TAU, 2011). This is hardly the most desirable situation: SEAs are done relatively quickly and are thus unable to probe with the depth and nuance that would be possible through more extended analytical work. Yet the SEA, coupled with societal debates on the issues that it and social movements had raised, became one of the primary justifications for the mining ban that the government passed, and is explicitly cited as one of the six *considerandums* in the law, and one of only two that refer to a formal data source.[16] This is not a criticism of the law—but it *is* a clear example of how critical policy decisions about mining and climate are being made in an evidence, data, and analysis-poor environment. The need for a much more fully elaborated research field on mining and climate change is both clear and urgent.

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[15] We are indebted to our reviewers for prompting this paragraph, which attempts to take up explicitly two of their suggestions. Our observation on ASM also draws on Bebbington and colleagues' recent research supported by the Climate and Land Use Alliance. We were unable (for reasons of space) to respond to one reviewer's recommendation that this paper also engage in one such application of our framework to a particular country context.

[16] The other formal data source is a global report by the United Nations Environmental Program (UNEP), which ranks El Salvador as the second most environmentally degraded country in the Americas, after Haiti.

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